

In every case these are denominator polynomials, while the numerator is a constant. These transfer functions can be changed to high-pass functions by the change of variable

$$s = 1/p \quad (12-125)$$

and to bandpass functions by

$$s = (p^2 + \omega_0^2)/Bp \quad (12-126)$$

where, in both cases, p = new frequency variable, B = bandwidth, $\omega_{c2} - \omega_{c1}$, and ω_0 = center frequency. Both are illustrated in Fig. 12-2. Alternatively, a low-pass-to-high-pass network transformation can be effected by the RC - CR transformation, in which resistors R are replaced by capacitors of value $1/R$ and capacitors C are replaced by resistors of value $1/C$. This must be followed by frequency and impedance scaling.

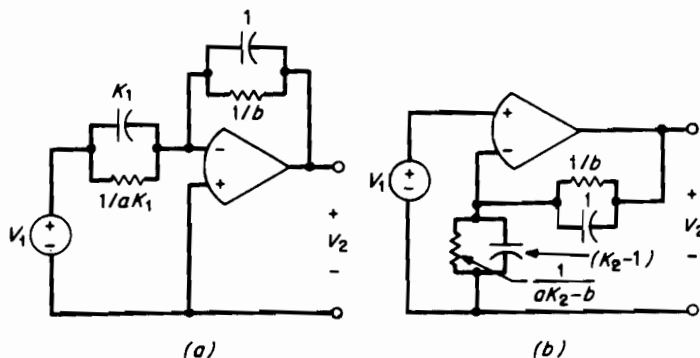


Fig. 12-34. (a) Inverting and (b) noninverting amplifiers to realize real poles.

Most active-network realizations require the designer to cascade second-order networks, each of which realizes one of the second-order denominator polynomials. When a first-order factor (real pole) is also needed, either of the networks of Fig. 12-34 can be used as the final element in the cascade. In Fig. 12-34a

$$\frac{V_2}{V_1}(s) = -K_1 \left(\frac{s + a}{s + b} \right) \quad (12-127)$$

and in Fig. 12-34b,

$$\frac{V_2}{V_1}(s) = K_2 \left(\frac{s + a}{s + b} \right) \quad (12-128)$$

In Fig. 12-34b, $K_2 \geq 1$, and $aK_2 \geq b$.

26. Synthetic Inductance Filters—Gyrators. It is possible to build filters with active elements that replace inductors. These realizations use the published tables for passive low-pass networks and the networks that are transformed from them. They also have the low-sensitivity properties of passive networks. One technique is based on the gyrator,¹⁴ a two-port with a z -matrix representation

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 0 & -a \\ a & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad (12-129)$$

where a is called the *gyration resistance*. A gyrator terminated in an impedance Z_L is shown in Fig. 12-35, and it is possible to show that

$$V_1/I_1 = Z_{IN} = a^2/Z_L \quad (12-130)$$

when $Z_L = 1/sC$,

$$Z_{IN} = a^2 sC \quad (12-131)$$

which is equivalent to an inductance of $a^2 C$. The problem then becomes one of choosing a and C .

Gyrators are available in integrated-circuit form

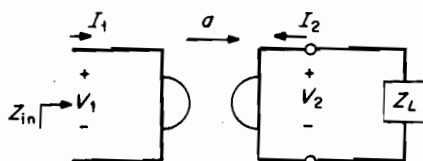


Fig. 12-35. Gyrator terminated with Z_L .

from several electronics manufacturers; the user simply adds the appropriate capacitor. Gyrator can also be built with operational amplifiers. One useful circuit is the Riordan gyrator,¹⁵ shown in Fig. 12-36 with Z_L as one of the five impedances it requires.

It can be shown that

$$\frac{V_1}{I_1} = Z_{IN} = \frac{Z_1 Z_2 Z_3}{Z_4} \frac{1}{Z_L} \quad (12-132)$$

When all Z 's are resistors R , and $Z_L = 1/sC$,

$$Z_{IN} = R^2 sC \quad (12-133)$$

This circuit must be used to replace a grounded inductor, e.g., in a high-pass network. If an ungrounded inductor is needed, the modification shown in Fig. 12-37 can be used, for which

$$Z_{IN} = R^2 sC \quad (12-134)$$

Other circuits, for which one side of the added capacitor C may be grounded, can also be used, though they may be more difficult to align.

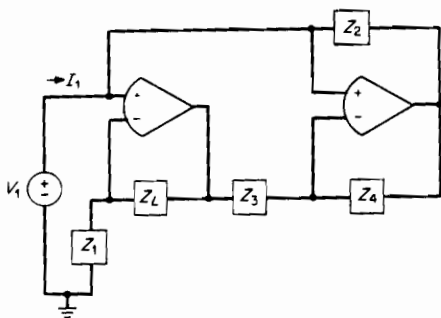


Fig. 12-36. Riordan gyrator.

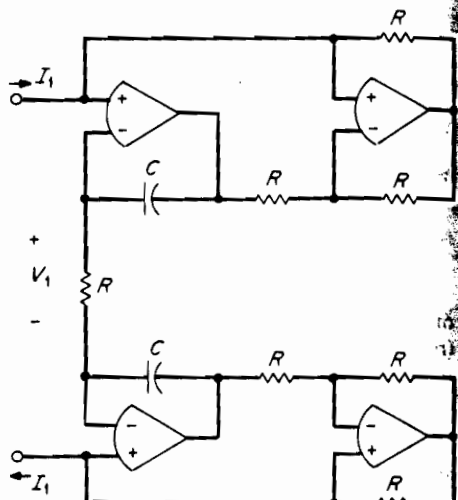


Fig. 12-37. Riordan-type back-to-back gyrator for floating inductors.

27. Synthetic Inductance Filters—Frequency-Dependent Negative Resistors. Bruton¹⁶ introduced a new type of circuit, called the *frequency-dependent negative resistor* (FDNR); the symbol is shown in Fig. 12-38. To use this idea, consider a new type of impedance scaling, in which passive elements become scaled by A/s ; this does not affect the transfer function:

Passive impedance		Scaled impedance
sL	$\rightarrow$	AL (12-135a)
R	$\rightarrow$	AR/s (12-135b)
$1/sC$	$\rightarrow$	A/Cs^2 (12-135c)

When $s = j\omega$ or $s^2 = -\omega^2$, the last element becomes

$$Z(j\omega) = -A/D\omega^2 \quad (12-136)$$

Fig. 12-38. FDNR representation.

a real, negative, frequency-dependent resistor. Thus, inductors are replaced by resistors, resistors by capacitors, and capacitors by FDNRs.

Bruton also gives a circuit for a FDNR, as a special case of the generalized impedance converter (GIC). It is similar to the gyrator and is shown in Fig. 12-39. For this circuit,

$$V_1/I_1 = Z_{IN} = Z_1 Z_3 Z_5 / Z_2 Z_4 \quad (12-137)$$

$$\text{when } Z_1 = Z_3 = 1/sC \quad (12-138)$$

$$Z_2 = Z_4 = Z_5 = R \quad (12-139)$$

$$Z_{IN} = 1/s^2 RC^2 \quad (12-140)$$

which is a FDNR. GICs are available from integrated-electronic-circuit manufacturers, and the user adds resistors and capacitors to make FDNRs. They can also be used to make gyrators. FDNRs are grounded when replacing capacitors in low-pass networks; floating FDNRs can be achieved by back-to-back GICs, as with gyrators.

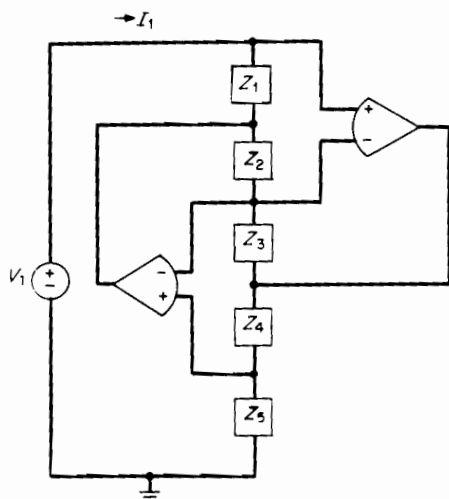


Fig. 12-39. Generalized impedance converter.

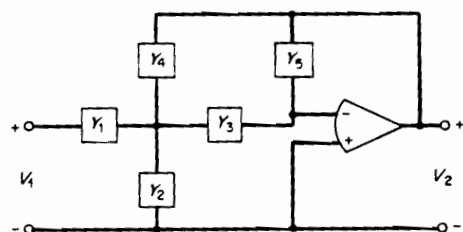


Fig. 12-40. A multiple-feedback, infinite-gain active realization for low-pass, high-pass, and bandpass filters. Table 12-15 indicates the choice of the five active elements for each case.

28. Infinite-Gain, Multiple-Feedback Realization.^{12,13} The circuit of Fig. 12-40 shows an operational amplifier with five passive elements, which are either resistors or capacitors. The general voltage transfer function is

$$\frac{V_2}{V_1} = \frac{-Y_1 Y_3}{Y_5(Y_1 + Y_2 + Y_3 + Y_4) + Y_3 Y_4} \quad (12-141)$$

Table 12-15 describes how the five passive elements can be chosen to implement a low-pass, high-pass, or bandpass network.

29. State-Variable Realization.¹² This network is a special but important type of infinite-gain realization. It has the advantage that low-pass, high-pass, and bandpass configurations can

TABLE 12-15 Element Choice for Active Filter Circuit of Fig. 12-40

Filter desired	Y_1	Y_2	Y_3	Y_4	Y_5
Low-pass	Resistor	Capacitor	Resistor	Resistor	Capacitor
High-pass	Capacitor	Resistor	Capacitor	Capacitor	Resistor
Bandpass	Resistor	Resistor	Capacitor	Capacitor	Resistor